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Fit For Purpose Unique Machinery Repair Techniques for Late in Life Production Facilities

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ExxonMobil



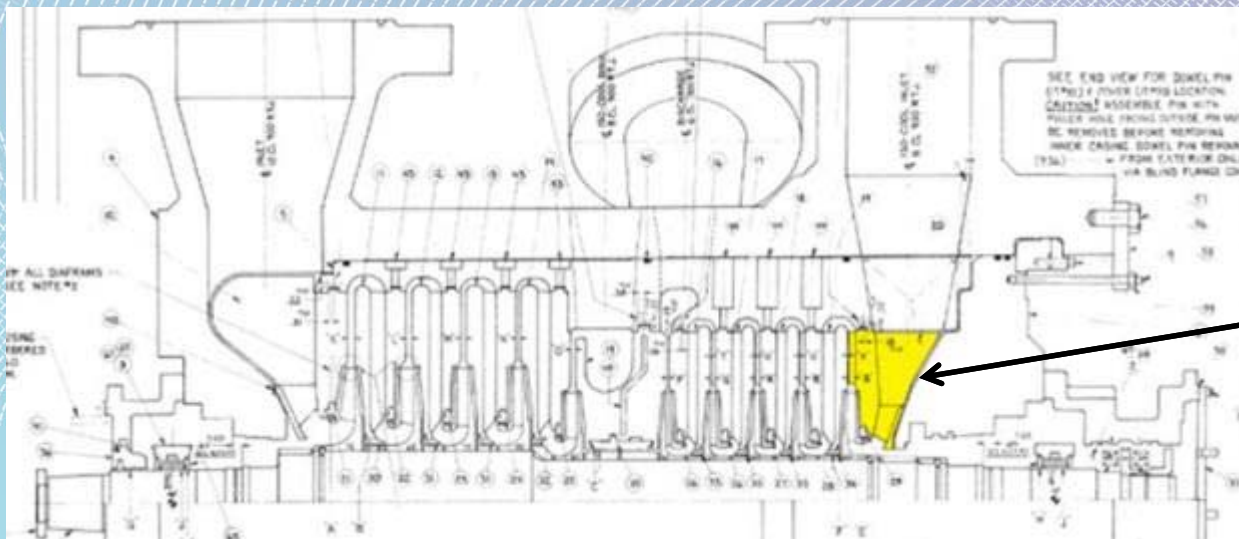
Introduction

- When machinery challenges arise in aging equipment within declining oil and gas facilities it requires innovative solutions taking into account life expectancy, production impact and declining production to establish fit for purpose solutions
- With good engineering, unique repairs can help limit production impact, extend equipment life and provide a more robust solution for current operating conditions
- Two case studies of novel equipment repairs are presented to demonstrate these principles:
 1. Eroded compressor diaphragm repair
 2. Coupling failures causing bent high speed gear rotors
- Focus was on restoring safe and reliable operation

Case Study 1 – Eroded Compressor Diaphragm

Background

- A compressor train removed for overhaul in June 2011
- HP inlet diaphragm vanes found eroded (70% material loss)
- >6 months of lead delivery time for new diaphragm



*Inlet Diaphragm
Highlighted in Yellow*

Compressor Assembly Cross Section



HP inlet diaphragm (bottom)



HP inlet diaphragm (top)



Eroded vanes(bottom half)



Eroded vanes(top half)

Brush Plating Summary

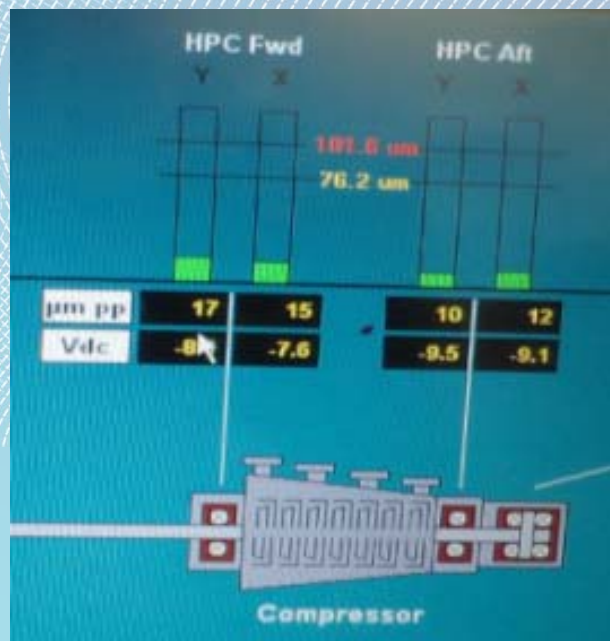
- 1 stop comprehensive engineering service provider
- Increase vane thickness (short term)
- Conduct trial run to ensure adhesion effectiveness
- Alloy deposition on vane
- Copper application – material buildup
- Nickel cap – bonding + hardness & erosion resistance



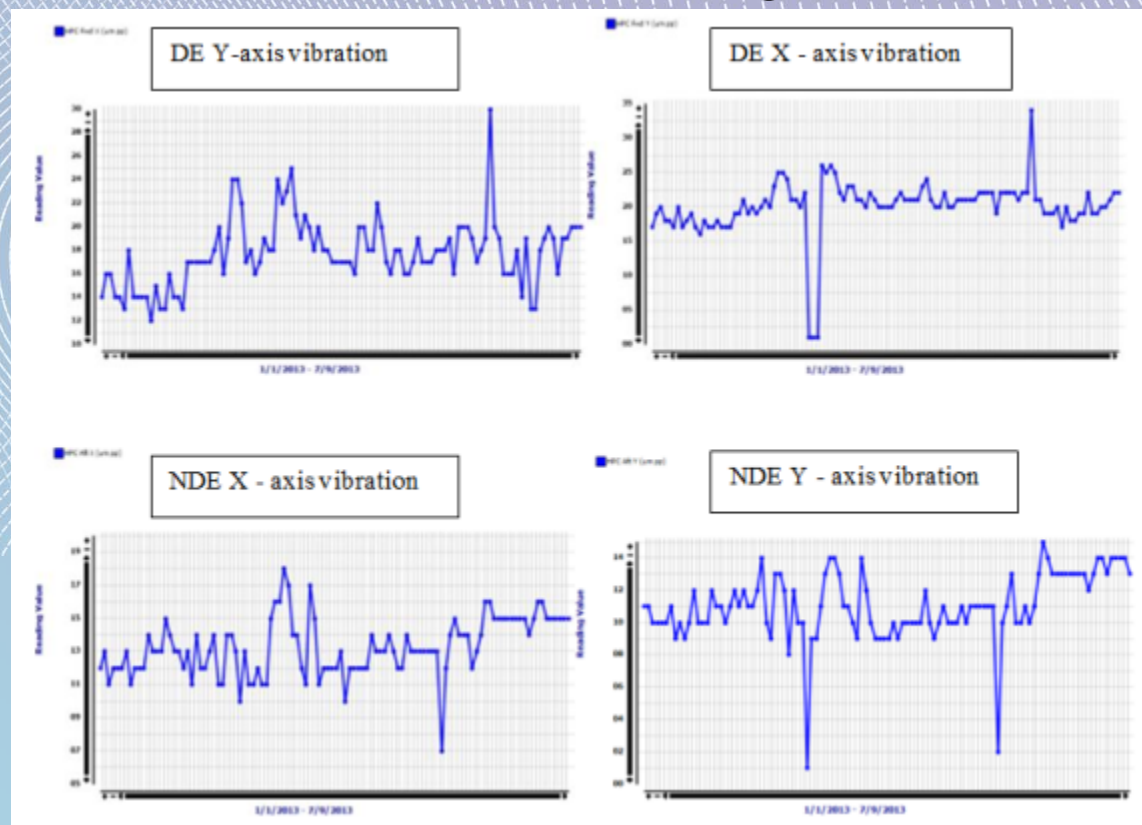
Repaired top half of diaphragm

Initial Concerns

- Debonding was a possibility with flakes coming off
- Gas flow obstruction or worst case, compressor overhaul
- No similar past experience with this type of repair
- Developed sample bend test – adhesion verification
- Monitor compressor vibration channels as safeguard



**Compressor vibration
HMI screenshot**



Vibration trend DE and NDE (Jan to Sep 2013)

Findings Post 12,000 Run Hours

	Bottom Half Vane Dimensions						Top Half Vane Dimensions					
Blade No.	Length		Thickness (mm)				Length		Thickness (mm)			
	Pre-Repair	Post 12k run hours	Front		Back		Pre-Repair	Post 12k run hours	Front		Back	
			Pre-repair	Post 12k run hours	Pre-repair	Post 12k run hours			Pre-repair	Post 12k run hours	Pre-repair	Post 12k run hours
1^	49	53	2.91	4.00	4.50	8.20	45	53	1.88	3.82	6.08	7.56
2^	49	53	2.80	3.35	8.04	8.50	47	53	1.40	3.95	6.36	8.70
5^	49	52	1.80	3.40	7.30	8.30	50	52	0.80	4.00	5.32	8.50
6^	46	52	1.00	3.90	6.11	7.70	44	52	1.60	4.20	3.73	7.75
7^	45	52	1.37	4.60	4.00	8.30	42	52	1.48	3.75	3.81	8.50

- ^ blades selected for brush-plating due to severe erosion
- blade thickness is measured 2mm away from the edge

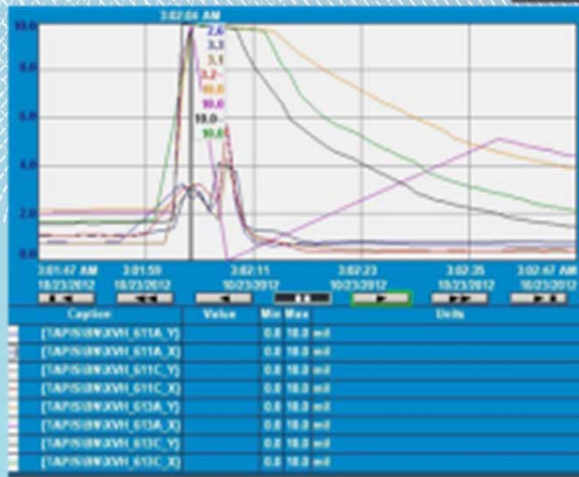
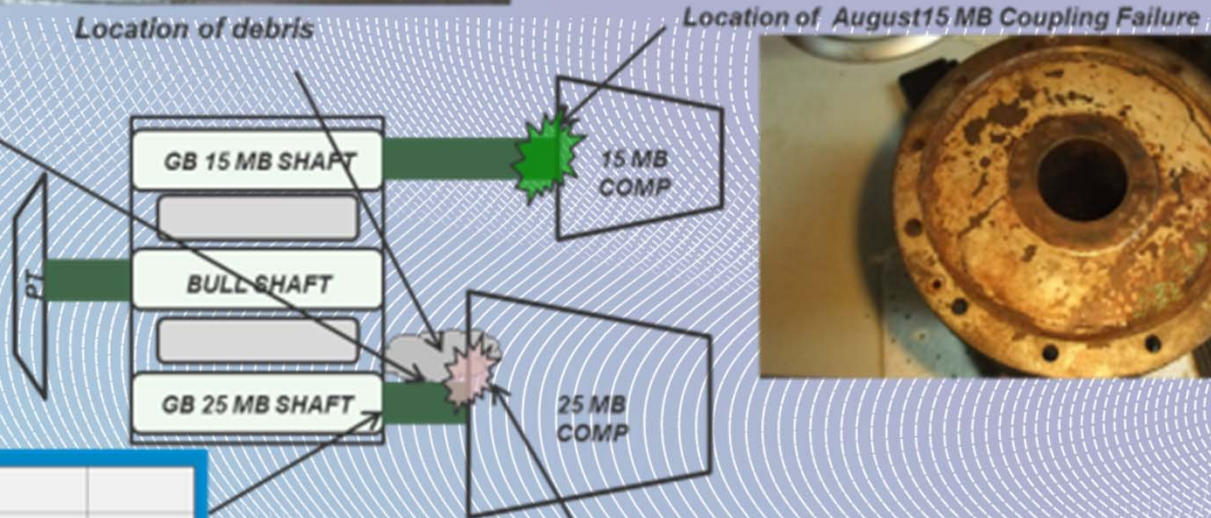


Diaphragm After Plating

Case Study 2 – Bent High Speed Gear Rotor

Background

- Gas turbine driven compressors used for re-injection of gas from oil producing wells, commissioned in 1979
- Compressors scheduled to run only 2 additional years due to depleting production
- Two separate failures a few weeks apart on two different parallel compressor trains – caused by changes in gas composition, shaft misalignment and 30 years of operation
- Gearbox to compressor coupling failure resulted in collateral damage to connected equipment
- Damage to output shaft of high speed gear rotor

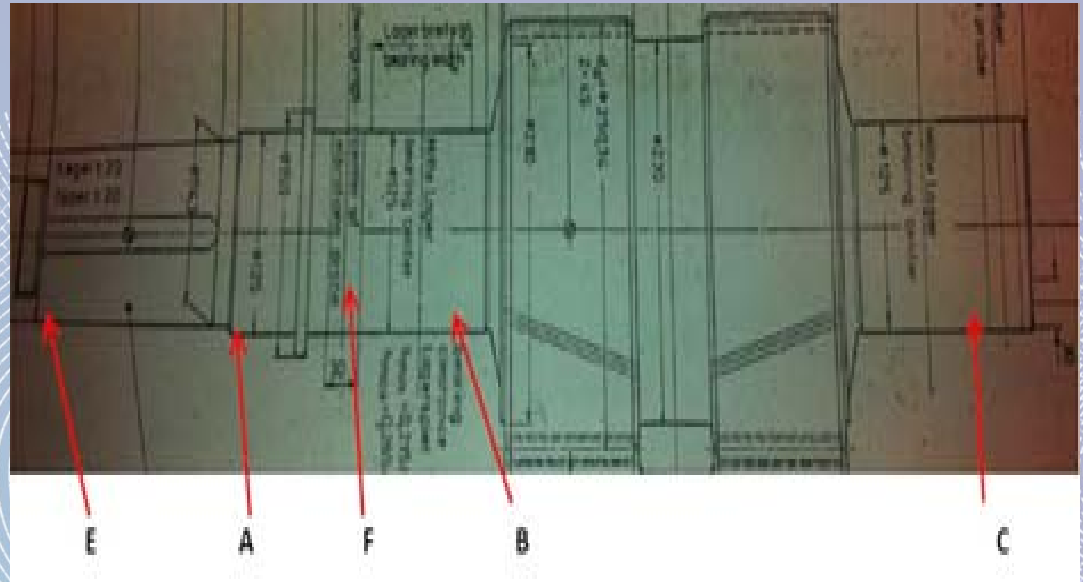


High Speed Gear Rotor Set Overview

- 5 rotors: 1 input, 2 output and 2 intermediate shafts
- Input Shaft is driven by the PT and is the only shaft with a thrust bearing (gear double helical design)
- Speed Ratio is the same on both output shafts (1.489)
- Output Shaft 1 Drives a larger Low Pressure Compressor
- Output Shaft 2 Drives a Smaller High Pressure Compressor
- Operating speed for either Output Shaft is approximately 11,000 rpm

High Speed Gear Rotor Damage Assessment

- First coupling failure (Train A) led to bent output shaft 1 driving Low Pressure Compressor Coupling
- Second coupling failure (Train B) led to bent output shaft 2 driving High Pressure Compressor Coupling



Dial Indicator Run-out Readings (units in mm)

	C=NDE Journal	B=DE Journal	A=Shoulder at Taper	E=End of Taper
TDC	0.0	0.0	0.0	0.0
90°	+0.07	0.0	-0.01	+0.29
180°	-0.05	-0.03	-0.01	+0.10
270°	-0.13	-0.02	0.0	-0.23

Procedure for Running-in Gear Rotors

Possibility to put together one set of gear rotors from remaining (undamaged) rotors

- Replaced damaged Output Shaft 1 from Train A with 'good' shaft from Train B

Potential for gear failure with over 30 years of wear in with different rotor

- Carried out tooth contact checks (verified 80% tooth contact area)
- Case-hardened gear tooth surfaces

Start-up Runs:

- Start up to Slow-roll (less than 1000 rpm)
- Start up to idle speed (approx 7000 rpm) for 24 hours with monitoring
- Start up to full load speed

Successfully reinstated one compressor train



Assembly and set up for on-site gear tooth contact verification

Workshop Background

- Regional mechanical workshop specializing in turbomachinery overhauls and repairs, and other machining and metallurgical work
- Areas of expertise:
 - **Assembly and disassembly**
 - **Thermal spray coating**
 - **PTA welding**
 - **Machining, grinding and turning**
 - **Cold work and build-up**
 - **Non-destructive tests**



60 Ton Hydraulic Press

Detailed Damage Assessment on Bent Rotor

- Workshop run-out readings were almost identical to those at site (TIR approximately 0.2 mm)
- Balancing checks verified tapered shaft eccentricity
- Magnetic Particle Imaging (MPI) and Ultrasonic testing (UT) demonstrated no subsurface cracks or defects
- Rockwell Hardness to confirm material identity and yield stress
- **ASSESSMENT:** Rotor damage was confined to eccentricity thus repair options could be pursued

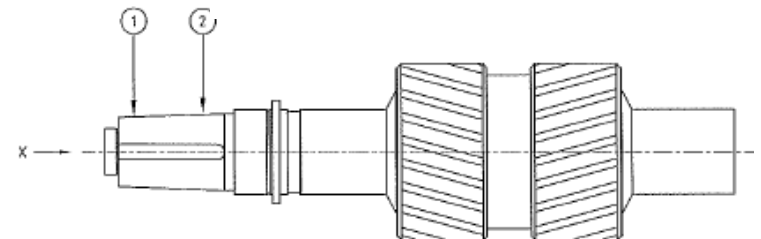
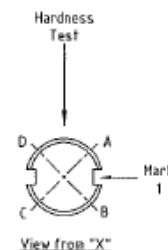


Above: MPI testing on gear teeth

Below: Hardness test location and results

Incoming Hardness Test, unit: HRC

POSITION / NO.	1	2
A - D	22.5	20.6
C - B	20.1	22.2



Repair Procedure and Execution on Bent Rotor

3 Step repair approach:

1. Hydraulic press to correct gross eccentricity
2. Surface grinding of shaft taper to restore 1:20 taper profile to coupling hub area
3. Full inspection to confirm no damage sustained in Steps 1 & 2

Outcome:

- Hydraulic press reduced shaft TIR from 0.2 mm to 0.05 mm
- Surface grinding successfully restored TIR to within 0.01 mm (shortened shaft by 1 mm)
- **SAFETY!:** Rotor balancing, MPI, UT and Die-penetrant tests showed rotor to be acceptable



Tapered Surface Grinding



*Completed Surface Finish
(roughness 0.266 micron)*

Conclusion Case Study 1 – Eroded Diaphragm

- Successful pilot repair – 2 years of operation
- Reduced compressor downtime
- Adequate for continued operation
- Useful reference for similar turbo machinery repairs

Conclusion Case Study 2 - Bent Gear Rotor

- Restored 1 Train to operation within 2 weeks
- Successful pilot repair on Low Pressure Compressor (LP) Gearbox Output Shaft
- Repeated Repair on HP Gearbox Output Shaft
- Both Compression Train Operating without gearbox issues for more than 18 months
- Useful reference for similar turbo machinery repairs

Overall Conclusions

These case studies highlight the need and benefit of innovative engineering for repairs of rotating equipment in aging oil and gas production facilities

- Focus was on restoring safe and reliable operation
- Taking into account life expectancy, declining production and production impact to establish fit for purpose solutions
- These factors drove the need to be open to unique engineered solutions that have proven to be successful
- Others can benefit from this experience in applications of these solutions to similar issues
- The support of the OEMs and repair shops played a key role in the success of these unique approaches

Acknowledgements - Case Study 1

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